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Power Requirements for Swimming a World-Record 50-m Front Crawl

Huub M. Toussaint and Martin Truijens

Peak performances in sport require the full deployment of all powers an athlete possesses. How factors like mechanical power output, technique, and drag, each in itself but also in concert with each other, determine swimming performance is the subject of inquiry in this case study.

At constant speed, a swimmer is subjected to the resistive forces of water, that is, drag (F_d) depending on a drag factor K and the swimming speed squared (v^2; see Equation 1). In order to overcome these resistive forces the swimmer has to generate power (P_d, ie, force times velocity) according to

$$P_d = F_d \cdot v = K \cdot v^2 \cdot v = K \cdot v^3 \quad (1)$$

In swimming, P_d is not equal to the total mechanical power (P_o) a swimmer has to deliver: The generation of propulsion in a fluid always leads to the loss of mechanical power that will be transferred in the form of kinetic energy from the swimmer to the fluid. Thus, in competitive swimming 2 important mechanical-power terms of the total power (P_o) can be discerned: power used beneficially to overcome drag (P_d) and power lost in giving water a kinetic-energy change (P_k). Hence,

$$P_o = P_d + P_k \quad (2)$$

The ratio between the useful mechanical power spent to overcome drag (P_d) and the total mechanical power output (P_o) is defined as the propelling efficiency, e_p.[1,2]

$$e_p = \frac{P_d}{P_o} = \frac{P_d}{P_d + P_k} \quad (3)$$

Combining Equation 1 with Equation 3, it appears that swimming speed depends on power output, a drag factor, and propelling efficiency:

$$v = \sqrt[3]{\frac{P_o \cdot e_p}{K}} \quad (4)$$

These theoretical considerations will be put to use by predicting individual power requirements for swimming a world record in the 50-m freestyle based on experimental data obtained with the MAD system (see Figure 1),[3] in which the swimmer pushes off from fixed pads with each stroke. These 16 push-off pads,

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placed 1.35 m apart, are attached to a 22-m-long, highly rigid aluminum rod that is mounted 0.8 m below the water surface. The rod is connected to a force transducer enabling direct measurement of push-off forces. Subjects use their arms only for propulsion; their legs are floated with a small buoy. If a constant swimming speed is maintained, the mean propelling force equals the mean drag force. Hence, swimming 1 lap on the system yields 1 data point for the speed-drag curve (see Figure 2).

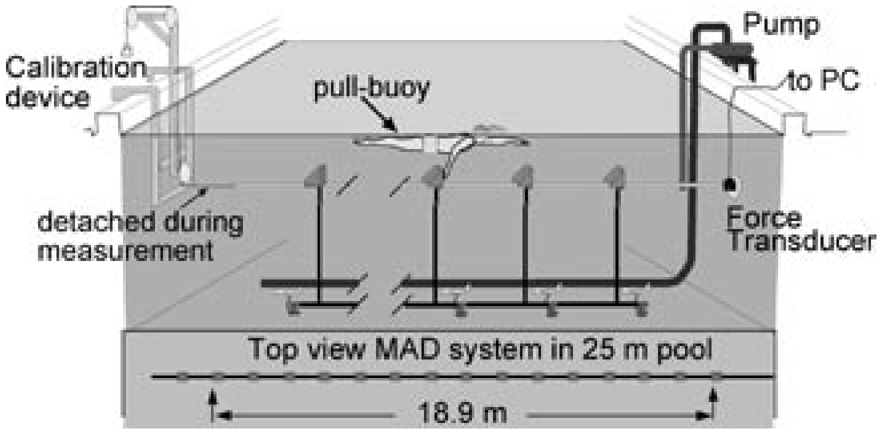

Figure 1 — System to measure active drag (MAD system).

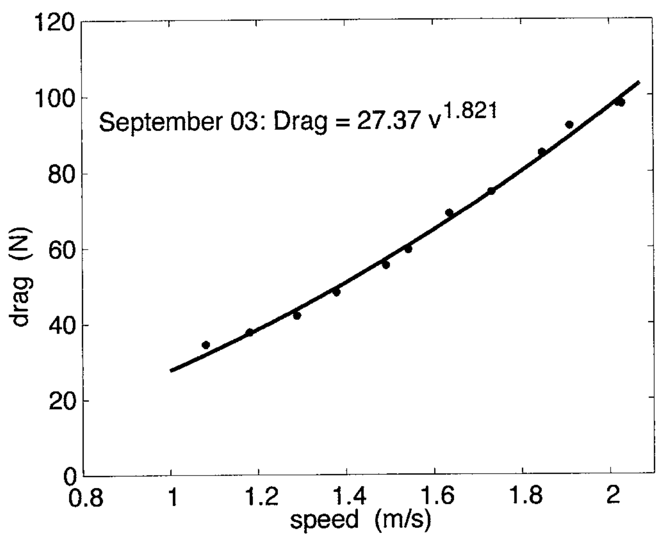

Figure 2 — Drag dependent on speed for subject JK.

The MAD system can also be used to estimate propelling efficiency. Given that the fixed push-off pads below the water enable the generation of propulsion without loss of energy to the water, all-out sprints performed on the MAD system enable faster swimming than all-out sprints when swimming "free." Considering that power to overcome drag relates to swimming speed cubed and assuming equal power output in two 25-m sprints (free and MAD), the ratio of speed cubed sprinting all-out "free" relative to the speed cubed sprinting all out on the MAD system reflects e_p:

$$e_{\mathrm{p}} = \frac{P_{\mathrm{d}}}{P_{\mathrm{o}}} = \frac{K \cdot v_{\mathrm{free}}^3}{K \cdot v_{\mathrm{MAD}}^3} = \frac{v_{\mathrm{free}}^3}{v_{\mathrm{MAD}}^3} \tag{5}$$

Swimmer JK is a world-class sprinter (50-m best time = 22.14 seconds) ranked fourth at the 2003 World Championships in Barcelona and was the silver medalist at the 2004 Olympic Games. The question was raised as to what power output is required for JK to break the 50-m front-crawl world record (21.64 seconds).

Drag dependent on speed for JK equals $27.37v^{1.821}$ (Figure 2). The maximal power output while swimming with arms only was found to be 220 W while reaching a speed of 2.06 m/s (March 2003, see Figure 3). Sprinting with arms only in a free-swimming condition, a speed of 1.88 m/s was obtained, yielding a calculated propulsive efficiency of 78%. When sprinting with arms and legs on the MAD system, a speed of 2.22 m/s was achieved, requiring a total power output of 281 W. With these performance factors a "free" swimming speed of 2.10 m/s was attained, the start not included, yielding a 50-m time of 22.14 seconds.

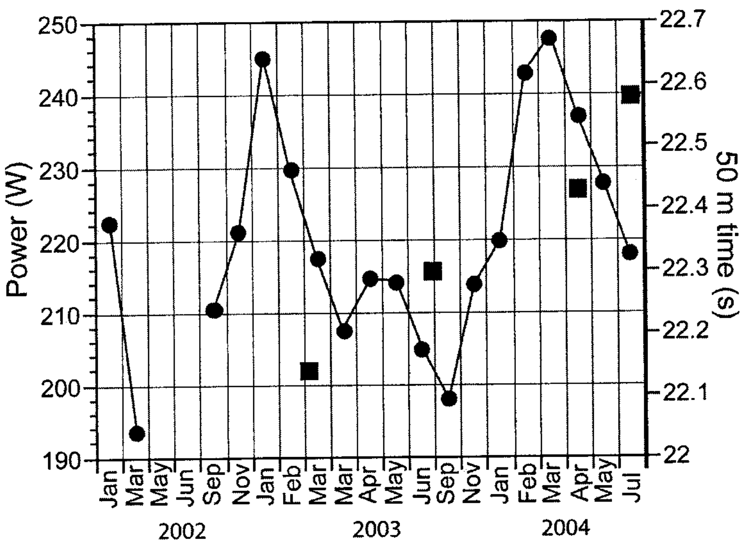

Figure 3 — Power output swimming arms only (dots) and 50-m time (squares) for subject JK. Note that not all tests are equally spaced in time.

Breaking the world record requires a speed improvement of at least 2.3% leading to a total power requirement of 320 W. Considering that the highest power output ever measured in JK is 297 W (swimming with arms and legs) and that an adequate taper should increase power output by about 10%,[4] setting a world record should be within this swimmer's reach, at least when physical-performance factors are taken into consideration.[5]

In this context it is interesting to note that the use of the MAD system as a water-based strength-training device has been evaluated. A study revealed that a group sprinting on the MAD system 3 times a week improved race times for free swimming on 50 m, 100 m, and 200 m[6] significantly more than a control group. This was attributed to a greater improvement in power measured on the MAD system relative to the control group.

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